Transient Science Cases & Requirements

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CMB-S4 Spring Collaboration Meeting

13 May 2022

CMB-S4

Measurement to Science — Transients

Science Goals:

- Open the mm-wave window onto the transient universe for multi-messenger astronomy.
- Explore the mm-wave transient sky.
- Measure the rate of mm-transients for the first time.
- Use the rate of mm-wave GRBs to constrain GRB mechanisms.
- Provide mm-wave variability and polarization measurements for stars and AGN.

Science Requirement 4.1: CMB-S4 shall detect GRB afterglows brighter than 30 mJy at 90 and 150 GHz over at least 50% of the sky and enable followup by issuing timely alerts to the community.

Science Requirement 4.2: CMB-S4 shall detect GRB afterglows brighter than 9 mJy at 90 and 150 GHz over at least 3% of the sky and enable followup by issuing timely alerts to the community.

Measurement Requirement 4.1: During normal operations, CMB-S4 shall measure I, Q, and U at 90 and 150 GHz, over $\geq$ 25% of the sky daily, with angular resolution $\leq$ 3.0 arcminutes and noise level $\leq$ 10 mJy/day. At least 90% of the time, the same $\geq$ 25% of the sky shall be observed for $\geq$ 5 consecutive days.

Measurement Requirement 4.2: During normal operations, CMB-S4 shall measure I, Q, and U at 90 and 150 GHz, over 3% of the sky daily, with angular resolution $\leq$ 3.0 arcminutes and noise level $\leq$ 3 mJy/day.

Note that it's just GRBs !

Doesn't actually say anything about alerts or time scales !

Transient Science Cases & Requirements: Outline

Transient Science cases that are *not* the design drivers:

- stellar flares
- AGN variability
- galactic compact objects
- supernovae
- special + rare nearby events

Note that I wasn't asked to talk about status sources !

But those have much less requirements and are mostly trivial.

Things the science community have asked for:

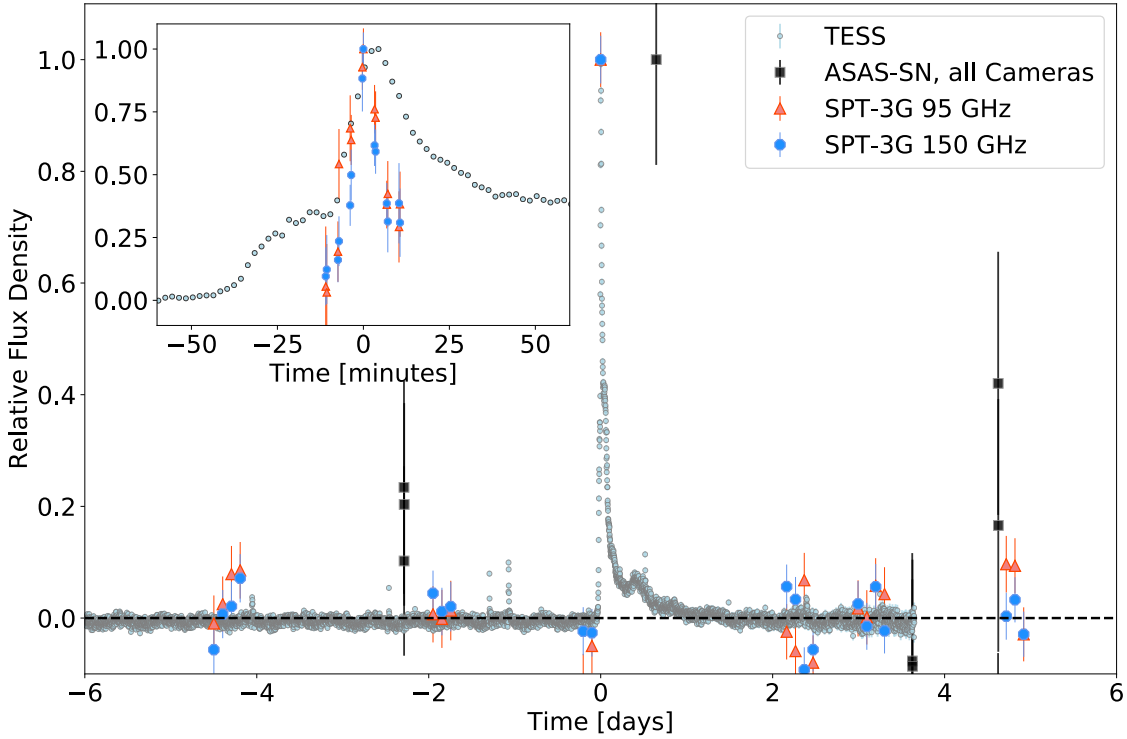
- *very* prompt processing
- external triggers
- higher time resolution
- polarization

This is what the People are asking for.

Science cases that are *not* design drivers: Stellar Flares

- The systematic discovery of bright flares from nearby stars was the first surprise when we opened the mm transient sky (ACT, Naess+21 ; SPT Guns+ 2021)
- The rates from SPT indicate 1000s of stellar flares on the sky per year … but they are FAST (minutes to hours) and will be mostly missed by the survey cadence.
- JV predicts the path for this science will be made clear by Stage III experiments in the next few years.

Guns+21 arXiv:2103.06166

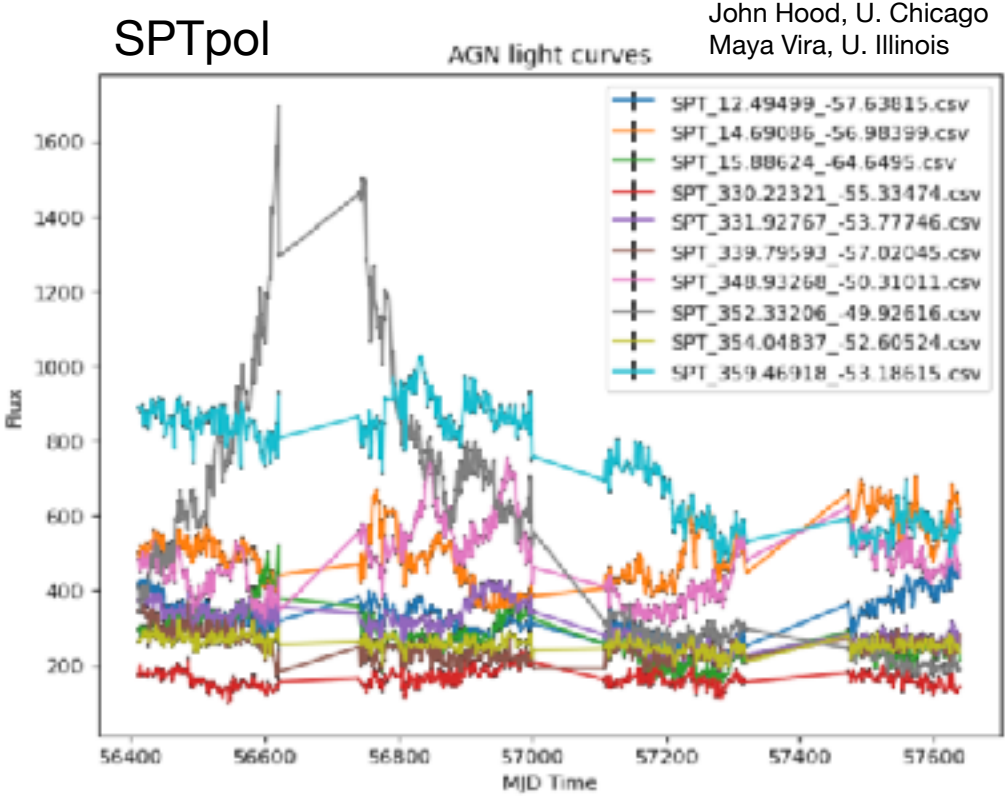


Science cases that are *not* design drivers: AGN Variability

mm light curves

- The brightest sources on the mm sky are blazars.
- Technically, these sources are “variable” and not transient.
- They will be an important background for any transient search, as they are constantly variable, and the faint ones will flare and look like a transient.
- They are interesting in their own right and there is a whole community that monitors these.
- There will be strong synergy with facilities at other wavelengths e.g. Fermi and VRO/LSST

Plot Credit:
John Hood, U. Chicago
Maya Vira, U. Illinois



Science cases that are *not* design drivers: Galactic Compact Sources

Sgr A* — The measurement of Faraday rotation would give us some hints about the density and magnetic field strength variations around the event horizon of the black hole.

X-ray binaries — The survey would cover a number of known X-ray binaries that are frequently or persistently bright in radio.

Classical Novae — The expected rate is a few per month in the whole Milky Way, so it would likely be a few months between Galactic Center region novae. As these observations would be unaffected by dust, there could be interesting constraints on rates.

Planetary Nebulae — Planetary nebula and protostar variability is a substantial cottage industry with current ground-based submm facilities.

Symbiotic Stars and SN Type 1 progenitors — Red giant-white dwarf binaries are a progenitor candidate for Type I supernovae. Due to extinction, the radio the best way to track their accretion rates and observations may discover new members of the class.

Magnetars — With sufficient time resolution, it may be possible to search for periodic emission from pulsars and magnetars.

Background:

ATLASGAL — The APEX telescope large area survey of the galaxy at 870 μm. ~100 deg^2 at 20” resolution with 295 bolometers

Science cases that are *not* design drivers: Supernovae

dunno, maybe we get lucky

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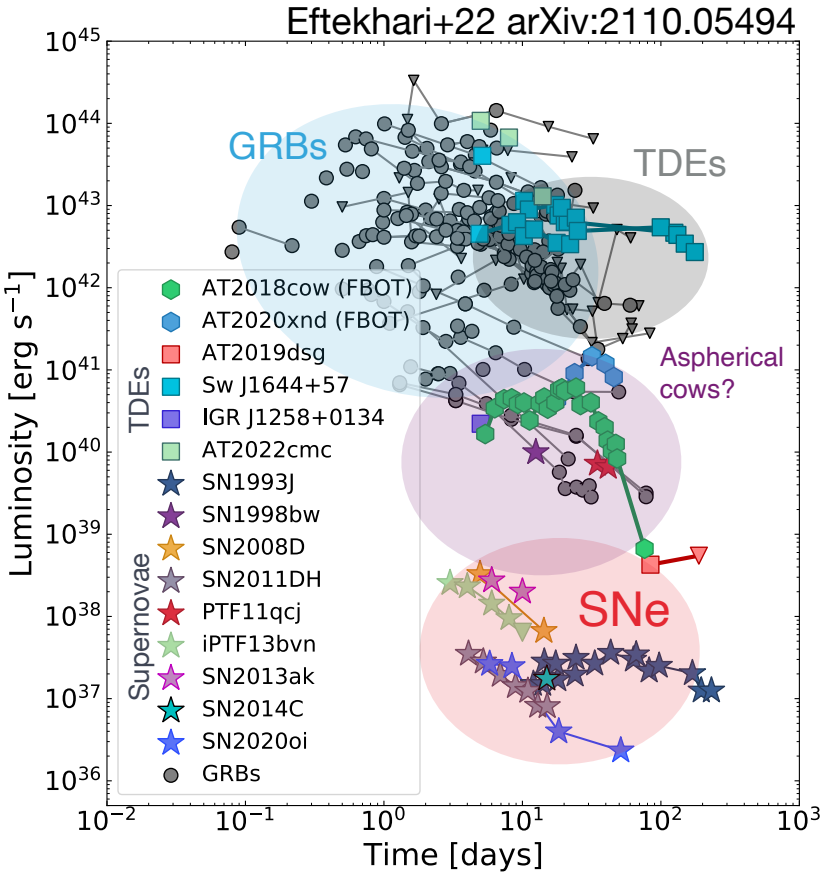
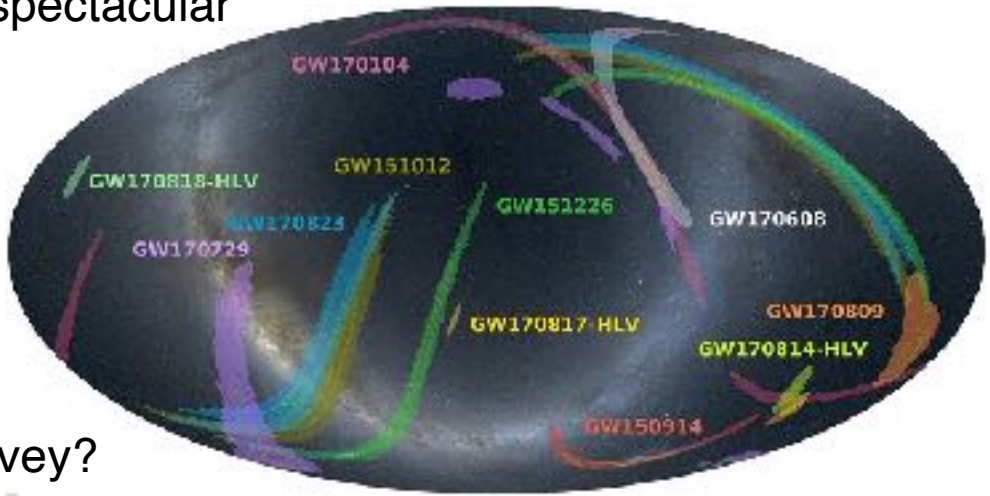


Science cases that are *not* design drivers: Special + Rare events

Q: What happens when a rare and spectacular event goes off nearby?



GW events
MMA events
a SNe in our galaxy ?

Will CMB-S4 pause the nominal survey?

Or will we just keep on with the nominal survey ?

JV has thoughts on this …

TLDR; I don't actually know what I'm doing

Science cases that are *not* design drivers: Discovery !

- There have been new+exciting results in the past year from CMB Stage-III experiments ACT & SPT. These are the first studies of their kind the field is evolving rapidly.
- Note that current Stage-III experiments studiously AVOID the galactic plane, where as next-generation surveys including CMB-S4 will include the galactic plane — this should produce a few more surprises.
- This adventure really just started and there may be a number of surprises left to discover. We are figuring out this variable mm-sky stuff on the fly!
- This science goal has a strong complementarity with other large projects (e.g. VRO/LSST, IceCube, LIGO, SKA, etc) and fields (e.g. MMA, time domain astrophysics, stellar astrophysics, etc)

Give the People What They Want

Important caveat:

I’m just reporting the things that get asked and discussed on the Sources & Transients calls

Don’t shoot me, I’m just the messenger

This will be part of an ongoing conversation over the next year or two.

Give the People What They Want: Higher Time Resolution

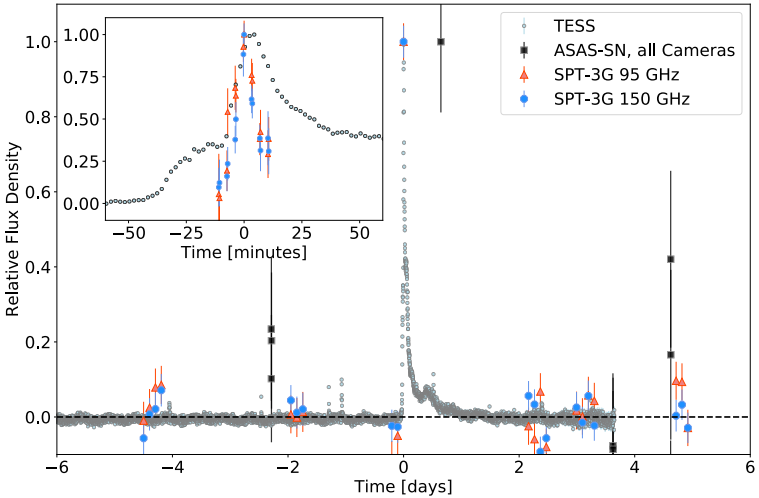
Guns+21 arXiv:2103.06166

Rather than extracting the time series from the daily coadd, we could extract from individual scan maps (like in Guns+21) or even the time streams.

This would *not* need to be done in real time. It could be done in “off-line” processing.

Depending on the particulars, this might want to be done on ~day time scale, or might only need to be done a ~year later.

JV’s opinion: This is an obvious thing to do. Once you have the raw data up North, it’s not a big deal, but would require someone to write some scripts to make it semi-automatic.



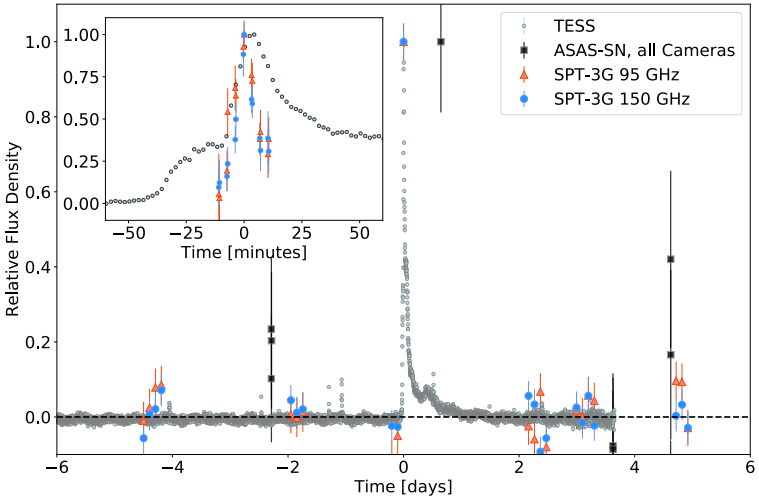
Give the People What They Want: *Very* Prompt Processing

Stellar-scale events will be minutes, not days.

We lose some sensitivity when averaging over the daily map.

We could think about triggering on faster time scales. This would require more computing on-site, or a low latency in sending data up North.

JV's opinion: Anything on minute time scale will happen too fast to point another telescope at, so it seems futile and unnecessary. Also, we probably wouldn't have the compute power on-site. But there will certainly be utility in off-line searches.



Give the People What They Want: Polarization

Polarization will be useful for characterizing sources, e.g., reverse-shock GRB events and AGN variability.

For off-line processing, this will not be an issue. It seems unnecessary for prompt processing, given the anticipated low-SNR of the detections.

JV's opinion: We will obviously provide polarization for off-line processing. It seems unnecessary for the prompt processing and alerts.

Plot Credit:
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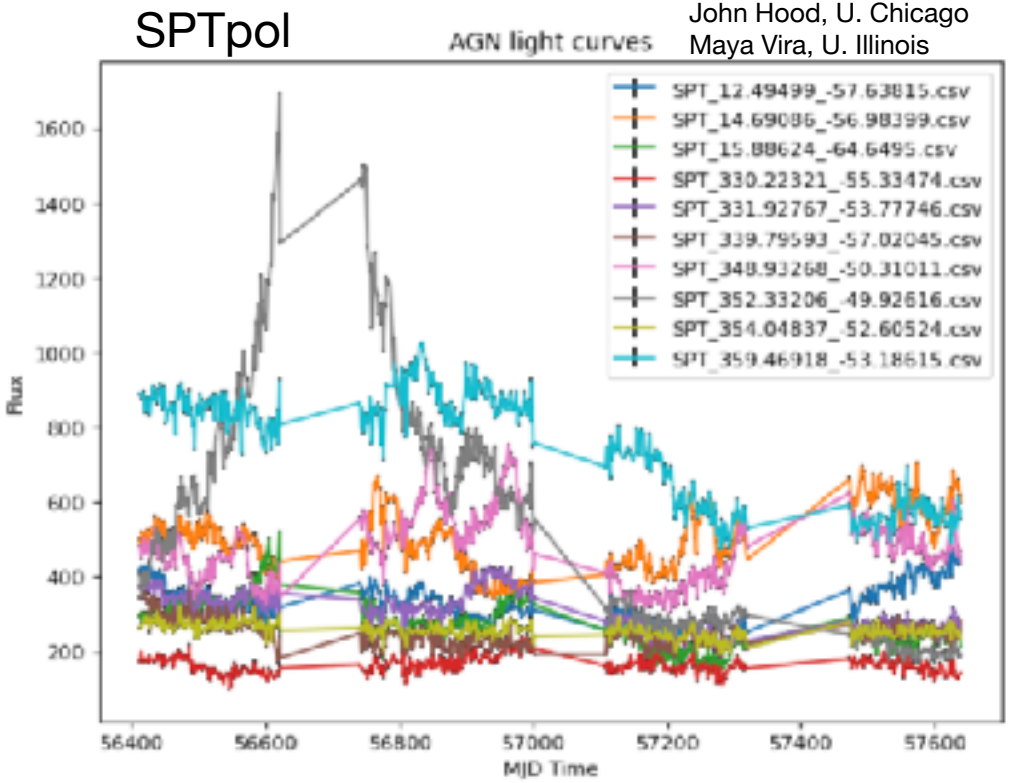
Maya Vira, U. Illinois

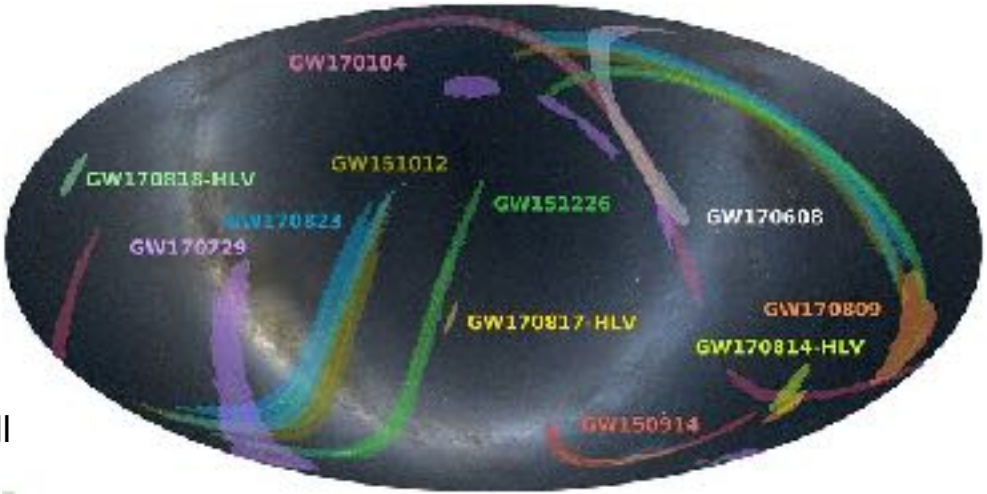


Give the People What They Want: External Triggers

Q: What happens when a rare and spectacular event goes off nearby?
e.g. : GW events, MMA events, a SNe in our galaxy ?

Will CMB-S4 pause the nominal survey?
Or will we just keep on with the nominal survey ?

JV's opinion: For anything unlocalized, CMB-S4 could be useful here. BUT, we will be surveying all the visible sky, anyhow, by default. For anything localized, you would point, e.g. ALMA. I think this is better suited to other facilities (e.g. Stage III experiments or e.g. APEX, JCMT, LMT



Give the People What They Want: Public Interface

Both the science collaboration and the public expect some sort of simple public alert for transient events and some sort of interface to access data on your favorite patch of sky.

All surveys have this (e.g. SDSS, Fermi, DES, etc).

NCSA is building one for SPT based off of DES. Other people also have similar services.

This isn't difficult or fancy, but needs to be done.

JV's opinion: Obviously we have to do this.

Give the People What They Want

This will obviously be an ongoing conversation with:

- Community
- Sources & Transients Working Group
- Science Council
- Funding Agencies
- *et cetera*…

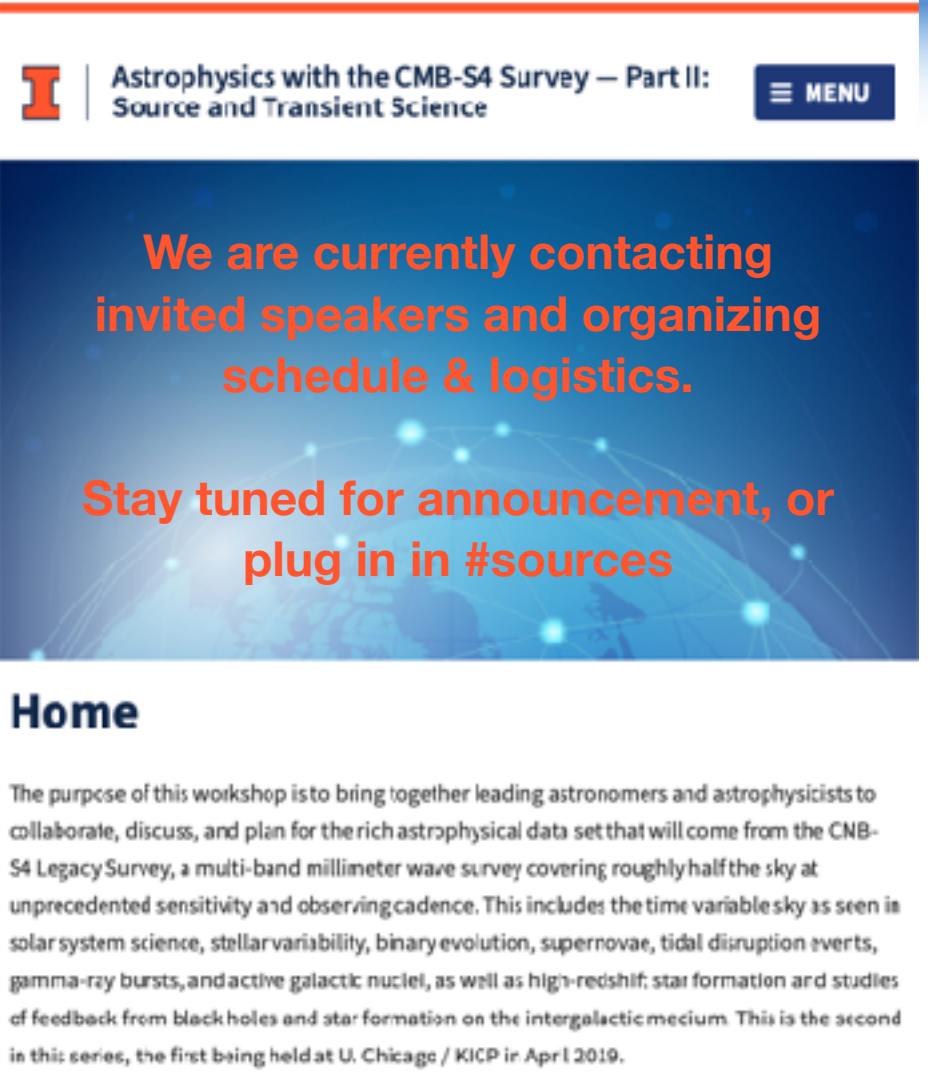
Astro2020 Decadal Review

Recommendation: The National Science Foundation and the Department of Energy should jointly pursue the design and implementation of the next generation ground-based cosmic microwave background experiment (CMB-S4).

Particularly compelling to the survey is the fact that these observations open the opportunity for systematic **time-domain** studies in this part of the electromagnetic spectrum for the first time.

An important requirement for our strong endorsement is that the project broadly **engage astronomers beyond the traditional CMB community**. CMB-S4 will produce data sets of unprecedented sensitivity, cadence and spectral coverage that will advance general astrophysics and open discovery space opportunities for diverse scientific communities. Previous CMB experiments have not had the charge or funding to make data rapidly available and generally usable. It is essential that CMB-S4 produce transient alerts, as well as calibrated maps in all bands and on all angular scales that are openly usable and accessible on as rapid a cadence as practical. This is not necessarily at the same level of precision needed for CMB analysis. This will both maximize and justify the significant national investment in the observatory, even if it **does require some nominal level of additional funding** to accomplish.

The RMS panel views CMB-S4 as a powerful, cosmology-focused experiment that would address Astro2020 priority science questions at a level that no other concepts can. In support of the project's long- term success, the RMS panel offers the following two suggestions for its implementation. First, the panel suggests that third-generation CMB experiments aligned with CMB-S4—specifically, the SPO and the "nominal" version of the SO—be high priorities for federal support. Besides training students and postdoctoral researchers, thereby empowering them to play vital future roles in CMB-S4, these experiments are poised to help retire technical risk for CMB-S4 and usefully inform its strategies for surveying the sky and removing foreground signals. Second, **the panel views it as appropriate for an experiment at the cost scale of CMB-S4 to be more "observatory-like" in seeking broad engagement with astronomers beyond the traditional CMB community, and ensuring that (for example) plans for data management and event alerts maximize opportunities for transient science to the extent possible without sacrificing the primary cosmology goals. The panel therefore suggests that an articulated plan for engaging the broader astronomical community be a precondition for the start of CMB-S4 funding.**



July 6 & 7
Hybrid — local in-person pods at UC Berkeley and U. Illinois / NCSA
Registration free, etc

Agenda:
Day 1: Transient / Variable / Time-domain Day:
- A) Galactic transients
- B) ExGal transients / variable

Day 2: Static Source Day:
- C) ExGal (AGN / SMGs / protoclusters)
- D) Galactic persistent sources

SOC:
Anna Ho, UC Berkeley
Tom Maccarone, Texas Tech University
Giuseppe Puglisi, Universita di Roma
Joaquin Vieira, U. Illinois / NCSA
Rachel Osten, STScI